ELSEVIER

Int. J. Production Economics 35 (1994) 107–114

international journal of
production economics

Trends in inventory management

M.C. Bonney

Department of Manufacturing Engineering and Operations Management, University of Nottingham, UK

Abstract

Inventory management is one of the success stories of recent years and it is changing rapidly in response to international competition and new technology. This paper examines some of these developments.

Inventory is a major investment in most companies. It strongly influences the internal flexibility of a company, e.g. by allowing production levels to change easily and by providing good delivery performance to customers. Yet inventory ties up working capital and space and it can suffer from obsolescence, deterioration and shrinkage. It can also add to administrative complexity. In recent years attention in manufacturing industry has concentrated on an 'inventory is waste' philosophy using JIT production, usually accompanied by visible 'pull' or consumer demand driven systems. The approach is also very effective in supermarket retailing and, at its best, provides very high stock turn and high profits to the company at the same time as providing good service and fresh items to customers at low cost,

Current changes in inventory management consider the total logistics chain under the term logistics management, place a greater emphasis on purchasing rather than producing in-house and use more international sourcing. Changes to recording methods include the use of different methods of information collection and processing, e.g. bar coding in retailing and manufacture and electronic exchange of information. Control methods are more computer based and are becoming part of increasingly integrated systems.

There are some obvious problems still to be solved. Procedures are needed to bring one-off analyses of inventory to become part of routine systems, work needs to be done to produce performance measures which are consistent between different levels of the organisation and the modelling of dynamic performance needs to become part of the design of our production–inventory systems. More fundamentally, we still do not know how to classify companies, let alone how to determine the best approach to inventory planning and control for a particular kind of company.

1. Introduction

Inventory is delightful. Its study abounds with problems of practical import and intellectual challenge. Our lives depend on inventory. Government and politics affect it and are affected by it. The treatment of inventory by enterprises of all sizes and type, public or private, in all political and economic systems is important.

Many changes are occurring in inventory planning. The approach to inventory is influenced by a country's economic performance, by the level of its internal activity, its debts, the hardness of its currency, the level of protectionism, the rate of inflation and much more. Fierce international competition, changes in political system, changes in technology, the development of increasingly integrated systems, increasing consumer expectations,

SSDI 0925-5373(93)E0108-8

and greater knowledge and availability of new methods are all having an impact on the inventory systems being used. This paper examines some of the changes and how these are influencing inventory planning and control.

2. What is inventory?

Inventory is normally taken to be synonymous with stock. Stock is something tangible, something to be mined, converted, created, transported and sold. To the individual it is the food in his larder, to the retailer it is the stock on the shelves of his shop, to the wholesaler it is the stock in his warehouse, to the manufacturer it is his raw material and finished goods and the intermediate stock, planned or unplanned, known as work in progress. Further back in the pipeline are stocks in the mines, in the extraction industries and with the primary producers such as steel.

From earliest times, inventory, particularly of food, was necessary to cover the time between harvests and to ensure survival even when a bad harvest occurred. Good storage protected against deterioration.

Inventory at any location is characterised by inputs (receipt or delivery into stores) and outputs (issues or delivery from stores). Stock in stores is needed only for those issues which are to be made before the next receipt is available for use. Additionally to cover uncertainty in timing, quality and quantity, safety stock may be held. Inventory at the wrong location or in the wrong state is not useful and will need further transport or processing to meet the potential user needs. It is common for shortages and surplus to occur simultaneously but at different locations. This manifests itself internationally with some nations having surplus food while other populations starve. In factories one may equivalently find too much raw materials and shortages at the finished part level, or treating capacity as analogous to stock, simultaneously under utilisation of resources and congestion. Each of these problems may be looked upon as the result of inappropriate distribution and control.

3. Decisions to be made

The main questions associated with inventory are: What should be stocked? Where should it be located? When should it be ordered? How much should be ordered? Answers to these questions should be consistent with investment and working capital strategy, service level judgments, and operational ease. However, inventory theory has tended to concentrate on providing answers to the last two questions, i.e. when and how much to order, probably because answers to these questions are needed on a day to day operational basis by clerks and by computer systems.

4. Inventory models

Inventory has many advantages. It can improve customer service by shortening lead times, it can provide organisational flexibility, it can buffer fluctuations between input and output rates, e.g. by ordering or manufacturing in bulk and selling in small quantities and it can smooth the manufacturing load on an organisation faced with fluctuating demand. It can be used to store capacity that would otherwise be lost.

Inventory also has disadvantages. it ties up working capital and space. It can suffer from obsolescence, deterioration and shrinkage. It can lead to administrative complexity and it can mask inefficiencies.

Inventory planning and control attempts to balance the advantages against the disadvantages of holding stock.

Inventory models are commonly used to determine when and how much to order. A typical model will relate the total cost of operating the system, C, to surplus cost C_1, shortage cost C_2, and initiation (i.e. ordering, set-up and planning) cost C_3 by means of a formula:

$$C = K_1C_1 + K_2C_2 + K_3C_3. \tag{1}$$

The values of K_i depend on the other parameters considered in the model such as the batch size, q. The most well known and, now, frequently criticised inventory control model is the Wilson lot-size model. The Wilson lot-size formula is static, i.e. relates to a constant demand pattern. It provides an answer to one of the previously listed questions – how much to order? By considering an individual stock item with a demand r per unit time and the surplus and ordering costs associated with holding and obtaining the item, the analysis derives the square root formula for q the so-called economic order quantity (EOQ)

$$q = \sqrt{\frac{2rC_3}{C_1}} \tag{2}$$

Traditional inventory control theory has developed two main approaches to answering the second question, when to order

- the re-order level (ROL) system,
- the re-order cycle (ROC) system.

With the ROL system an order is placed for a stock replenishment when the re-order level s is reached. Appropriate choice of s provides protection against stochastic demand. The re-order quantity has previously been determined to be q. Hence, this system is sometimes called the (s, q) system. In it, the order quantity q remains constant but the time between orders varies in response to the variability in demand. This provides natural feedback control. By contrast, in the ROC system, an order is placed at a regular review time, t, e.g. every week. The order quantity, calculated at the time of review, is determined as the difference between a requisitioning objective, S, and the stock in hand and on order. Sometimes an order will be placed only if the stock is below a ROL s. In this case, the system becomes the well documented (s, S) system. Many inventory control system variants involving s, S, q, and t exist.

A model cannot be better than the validity of the underlying assumptions. The Wilson lot-size formula ignores inter-relationships with other parts which may arise from, e.g., the use of common resources, it suggests that there is a single best answer and it assumes that the surplus and ordering costs are fixed. It is therefore not surprising that it suggests answers which are not necessarily usable in the real world. However, even a model producing an answer unusable in an operating sense may be a useful aid to understanding. For example, this simple EOQ model shows that the cost/unit based on the variables considered does not change much with change of batch size. In other words, the analysis shows, within limits, that one may choose smaller batch sizes without worrying too much about the costs. Secondly the analysis shows that by reducing the set-up cost then the batch size can be reduced. An early set of arguments about the EOQ were the papers by Eilon [1] and Tate [2]. Other analyses take account of queueing effects and show that the optimum batch size should be dependent on the utilisation of the manufacturing facilities. This was used by Bonney [3]. More recently Byrne [4] studied, by means of a factory wide simulation, the effect of choosing batch sizes to correspond with changes in technology such as occur with a set-up reduction programme. These analyses, referred to again later, highlight the inter-relationship between different parts queueing for the same resource.

Inventory control has been a fertile ground for the theoretician and inventory model developments have continued over the years. However, a criticism which may be levelled against most inventory models is that they are static and in order to get a dynamic view of the system, simulation is necessary.

5. Wider inventory problems

Any problem with surplus, shortage and set-up costs may be considered as an inventory problem. Under this definition inventory problems include most resource planning decisions such as the provision of productive capacity, theatre seats, air line seats, supermarket checkout stations, operating theatres, water reservoirs, health care resources and trained manpower. Expressed in these terms inventory planning and control may be an attractive way of looking at some queueing problems and vice versa. These problems will not be discussed further in this paper.

6. Inventory objectives – An international view

Inventory planning is affected by broader economic, social and political issues – in the provision of resources and by the ability of governments to influence the costs of surplus and shortage, by creating artificial trade barriers, by changing interest rates, by changing the money supply or by pursuing inflationary or anti-inflationary policies. Each will radically change the costs of inputs and the price that can be charged for outputs. They will also change the costs of holding stock and the likely demand.

In capitalist societies the main objective of an enterprise is to make money. This is frequently achieved by providing good customer service either by satisfying the demand that exists or by influencing demand by advertising, price or other incentives. Thus, most retailers will have sales, i.e. periods at which goods are offered at reduced prices, in the New Year and the Summer to counter what would otherwise be times of low activity. In western countries the traditional view has been that inventory is an investmemt and it is treated on the balance sheets of companies as an asset. This may have been true when product life cycles were long and model changes were few, but it is no longer generally applicable that inventory is an asset and there has been a move in many western companies to adopt Japanese ideas and to treat inventory as one of the kinds of waste to be eliminated.

In Eastern block countries, the emphases have been on the central planning of production and inventory and on protecting markets from competition. Protectionism offers potential advantages for coordination and economies of scale and as transitional arrangements to protect industries and particularly start-up companies, until they have become competitive. In practice, however, performance has often fallen short of requirements to meet production targets, quality levels and consumer needs. Having recognised these problems, the same countries are now attempting to lift their productivity and consumer satisfaction performance up to western levels within the obvious constraints provided by shortage of working capital. A similar situation appears to exist in Brazil where after years of protectionism, the new government is throwing its doors open to international competition as a way to combat inefficiencies that seem to have arisen.

The world is changing rapidly. Trade barriers are coming down. Sourcing of goods is international. Product life cycles are reducing so much that design and manufacture need to be considered concurrently rather than sequentially. Organisations are changing to deal with this new situation. Lead times need to reduce. A possible solution is to manufacture just-in-time. In the area of quality there are progressive moves towards zero defects with supplier quality assurance, quality circles, building quality into design, improved training, etc. Moves to BS5750 and ISO 9000 puts a great emphasis on traceability and affects inventory control requirements and possibilities.

Technology is also changing. Computers are commonplace. Software packages exist for operational control. They perform the processing and presentation required for the usual operational inventory functions such as stock recording, stock valuation, Pareto analysis and, of course, determining replenishment quantities. The latter may often be linked with standard forecasting methods. Additionally stock analyses such as identifying slow movers, shortages and stock turn may be performed. The ready availability of personal computers and appropriate software has meant that even relatively small organisations can use computer methods effectively for inventory planning and control. Software also exists for simulating proposed inventory systems. This means that the performance of proposed systems when faced with typical demands may be tested prior to implementation. The use of bar coding and laser readers has revolutionised supermarkets and some manufacturing plants. This and other shop floor data collection systems mean that status recording is carried out in real time and stock records are completely up to date. There are changes in material handling based on increasing use of conveyors, AGVs, robots and automatic warehouse. There are also changes in manufacturing processes through the use of CNC, DNC, robots, etc. Processing and materials handling are being networked to management control systems to create computer controlled flexible manufacturing cells and integrated manufacturing systems. Flexible manufacturing methods also meet the need to be able to manufacture in variable quantities. The component classification/group technology methods that go in parallel with flexible manufacturing also reduce variety and ease set-up cost reduction. Each of these developments offers opportunities to reduce inventory.

Finally, there is growth in our understanding of inventory systems through better mathematical modelling and simulation including control theory and industrial dynamics. These can take account of the effect of system dynamics and hierarchical planning in the complete logistics chain.

7. Different approaches to inventory planning

Inventory is of concern to

- individuals as it affects the quality of their life,
- retailers wishing to supply their customers without too much waste or loss of custom,
- manufacturers planning their production,
- industries facing over or under capacity,
- nations seeking to maintain employment and develop competitive industries.

The inter-dependence of one organisation with another suggests that we should be interested in the logistics and supply chain management both within and external to that company. By the logistics chain is meant the flow of materials from suppliers through the receiving organisation and then on to the customer. Integrating key supplies is an essential part of the JIT concept as discussed by Fieten [5] but there is the danger of the production and inventory control systems in the supply chain amplifying changes of real demand.

Two main approaches exist to planning production and inventory. In the first a desired inventory level is chosen and a production level is then determined which maintains the planned inventory. In the second approach a desired production level is chosen and the level of inventory then follow as a consequence. This consequential inventory depends on the lead times and batch sizes used and is often augmented by an additional planned safety stock.

Some researchers subdivide production inventory systems into push and pull systems. The original pull systems were the ROL and the ROC systems. ROL and ROC systems were found to have many disadvantages particularly the ordering of unwanted items and items in unbalanced sets. It was found that amplification of demand, and self-induced cyclical changes can occur. Starting in the 1960s, and gathering pace in the 1970s, and 1980s there was a move in the West to use materials requirement planning (MRP). MRP is considered by most authors to be a push system attempting to produce items in balanced sets to meet the needs of the master production schedule, but it is clear from the information flow, that there is also a pull element.

In recent years there has been a move towards the use of JIT production methods. JIT is a philosophy which includes the concept that inventory is waste and aims to shorten lead times and use a demand pull approach. This means that companies only make what is required when it is required. Associated with JIT is a requirement for the reduction of set-up times and batch sizes, and for high-quality (zero defect) production. Although the material and information flow is structurally the same as in a ROL system, the other parts of the system have been adjusted so that one can produce in small quantities. In batch size terms the initiation cost C_3 is now so small that the batch size q may also be small. Also because it is demand pull the quality made is the quantity needed and not an arbitrary 'economic' order quantity. With the continuous flow production used lead times are also small. Obsolescence is low.

Williams et al. [6] compare stock levels in British and Japanese manufacturing over the period 1955–1986. The Japanese managed to achieve phenomenal stock reductions over the period from 1959 to 1969 reducing their sales cover from 9.2 to 6.2 weeks since when it has not improved. Over the 1973–1983 period, despite improvements in individual sectors, average Japanese stocks were equal to 6.8 weeks while British manufacturing, typical of other Western economies, stocks were 10.8 weeks of sales. Further suggestions in this paper are that the financial advantage of reducing stock are greatly underestimated and the failure of JIT in many British firms is a result of limited understanding and commitment. JIT methods are discussed in many recent books, e.g. [7]. The implication of the literature would appear to be that it has been practical operational changes, e.g. visibility and improved quality rather than any dramatic new theory which has made the major impact on inventory levels.

Another philosophy which has received a lot of attention of recent years is OPT[1]. A balanced review of this approach appears in Frizelle [8]. OPT concentrates on the flow through capacity constrained resources or bottlenecks. The logic of OPT is that the cost of an hour wasted at a bottleneck machine is high and a non-bottleneck machine is virtually zero. Two batch sizes, the process batch and the transfer batch are identified. Large process batches and small transfer batches and tight scheduling are used at bottleneck machines. Small process batches and small transfer batches may be used elsewhere. The effect is that one can get high utilisation and a coordinated flow of material through the bottlenecks by taking advantage of the flexibility provided by the non-bottlenecks. This has been expressed as the drum, buffer and rope concept, i.e. the bottleneck beats a coordinating drum, the rope pulls the required items to the bottleneck and a time buffer exists before the bottleneck to ensure high utilisation even if there is a delay in the delivery.

8. Performance measures

The main objective of capitalist organisations is to make money. In corporate terms this can be translated into improving profit, return on investment and cash flow. An interesting part of the OPT ideas is an attempt to derive a set of operational measures, namely throughput, inventory and operating expense which are consistent with the corporate objectives of improving profit, return on investment and cash flow.

Attempts to get consistency of objectives in hierarchical planning are also being made by other workers. Much work remain to be done but consistency is likely to be one of the key influences on the intellectual basis of future decision support systems particularly those related to intelligent, integrated manufacturing systems. One possibility is that ROI could be used at the operational level as well as at the strategic level. Johnston [9, 10] chose safety stocks in merchandising systems based on a ROI criterion. The basic idea is that safety stock is an investment which should give comparable returns to other investments. Johnston uses the company's chosen inventory level to determine the imputed cost of a lost sale. Similarly, Bonney [3] examined way of choosing average shop floor utilisation to maximise ROI and Byrne and O'Grady [4] showed how to choose batch sizes *under current conditions* to maximise ROI. In addition to consistency in the objectives there is a need for accounting data to be relevant to the decisions under consideration, e.g. what are the real costs and savings associated with reducing inventory, reducing variety, improving quality, improving delivery, performance, etc.

[1]OPT is a registered trademark of Scheduling Technology Limited.

9. Control models

Many types of production and inventory control systems exist. Hence, within a specific logistics chain could occur ROL, ROC, MRP, JIT and other systems. Different systems may be distinguished structurally by the different information flows. Additionally, specific companies will have different times for purchasing, delivery and manufacture, different degrees of uncertainty about demand and supply and different quality levels. The information flows, delays, lot sizing and uncertainty, real or system created, can interact with forecasting rules and inventory control rules to create fluctuations in stock levels and demand at higher levels.

Control approaches are increasingly able to provide understanding on how to design systems which provide an appropriate balance between highly fluctuating demand and highly fluctuating stocks. Dynamic analysis of these problems using analytical and simulation approaches has been carried out by many researchers. Examples include Simon [11], who analysed simple system representations using Laplace transform methods. Popplewell and Bonney [12] and Bonney and Popplewell [13], who used z-transforms to examine ROC and MRP systems, O'Grady and Bonney [14], who investigated range of production and inventory problems using modern control theory. Forrester [15], who introduced the industrial dynamics simulation approach and Towill [16], who combined the analytic and simulation approach. A review of control theory concepts in production and inventory control appears in Axsater [17]. Towill [18] examines the complementarity of classical control theory to other control approaches.

A research team at Nottingham (see e.g. [19–21]) are currently developing hierarchical methods of systems analysis and design based on Petri-nets. This work examines a framework for computer-aided production management (CAPM) based on the inter-relationships between hierarchical planning, simulation, transaction recording, management information systems, performance objectives and measures. The representation of actual companies immediately highlights the control nature of the production and inventory control systems. The advantage of using Petri-nets is that the system representation can become a simulation and the operational control of the system. Commercial software such as MRP can be used to control the transitions. In other words the approach offers to provide a common method of representing the dynamics of complex systems in theory, simulation and practice and so will allow inventory to be investigated at the same time as other system changes.

10. The future

It would seems that by combining the committed Japanese approach with the use of a framework which includes hierarchical planning and simulation, a management information system and a consistent set of performance measures, there is potential for further advances to be made in inventory planning and control. The current trends towards more purchasing and less in-house production, improving quality, rapidly changing consumer taste and demand, increased international competition, reduced product life cycles, increased rate of technological change, greater system integration, tight money, high interest rates, pressures to reduce lead times and reduce stock are likely to continue. But successful inventory reduction appear likely to be limited to the relatively small number of organisations which can provide the commitment to improving their whole systems. Although the pressures and rewards are there, improvements are not easy.

If the lead times are small enough and the market exists, then many problem disappear for the individual company. But on an international basis there will remain the problems arising from the disparity of wealth between different parts of the world and problems associated with the greening of the planet. Each will force a rethink on the location of manufacture, the materials used, and the processing and packaging methods used. We shall also need to examine the consequences in terms of energy used, wealth redistribution and minimising waste in the classic sense. Each of these changes will need to be translated into appropriate inventory strategies and consistent operational policies. It is by no means certain that overall there will be less inventory. However it is clear that inventory control methods and an understanding of the effects they will have are going to be essential ingredients of the fundamental rethink needed to overcome the problems of our simultaneously rich and poor, simultaneously in surplus and in shortage, throw away society.

References

[1] Eilon, S., 1964. Dragons in pursuit of the EBQ. Oper. Res. Quart., 15:347.

[2] Tate, T.B., 1964. In defence of the economic batch quantity. Oper. Res. Quart., 15:329.

[3] Bonney, M.C., 1982. Inventory investment consequences of different production control strategies, in: A. Chikàn (ed.) New Results in Inventory Research, pp. 417–423; Proc. 2nd Int. Symp. on Inventories, Budapest, 1982. Elsevier.

[4] Byrne, M.D. and O'Grady, P.J., 1987. Lot sizing in a practical manufacturing system'. Eng. Costs Prod. Econom., 13: 13–26.

[5] Fieten, R., 1989. Integrating key supplies, essential part of a just-in time concept. Eng. Costs and Prod. Econom., 15: 185–190.

[6] Williams, K., Williams, J. and Haslem, C., 1989. Why take the stock out? Britain vs. Japan. IJOPM, 9: 91–105.

[7] Voss, C.A., 1987. Just in time manufacture. International Trends in Manufacturing Technology. IFS publication Ltd., UK, Springer, Berlin.

[8] Frizelle, J.D.M., 1989. OPT in perspective. Adv. Manuf. Eng., 1: 74–80.

[9] Johnston, F.R., 1980. Strategic management decisions and a stock control system. Proc. 15th Eur. Tech. Conf., BPICS, Blackpool, 1980.

[10] Johnston, F.R., 1980. An interactive stock control system with a strategic management role. J. Oper. Res. Soc., 31: 1069–1084.

[11] Simon, H.A., 1952. On the application of Servomechanism Theory in the study of production control. Econometrica, 20: 247–268.

[12] Popplewell, K. and Bonney, M.C., 1987. The application of discrete linear control theory to the analysis and simulation of multi-product, multi-level production control systems. Int. J. Prod. Res., 25: 45–56.

[13] Bonney, M.C. and Popplewell, K., 1989. Design of production control systems: choice of system structure and systems implementation sequence. Eng. Costs Prod. Econom., 15: 169–174.

[14] O'Grady, P.J. and Bonney, M.C., 1985. The optimum behaviour of a multi-Echelon production and inventory system. Eng. Costs Prod. Econom., 9: 23–32.

[15] Forrester, J.W., 1961. Industrial Dynamics. MIT Press, Cambridge, MA.

[16] Towill, D.R., 1982. Dynamic analysis of an inventory and order based production control system. Int. J. Prod. Res., 20: 671–687.

[17] Axsater, S., 1985. Control theory concepts in production and inventory control. Int. J. Systems Sci., 16: 161–169.

[18] Towill, D.R., 1992. The practical use of control theory in manufacturing systems design and manufacturing management. J. Systems Eng., 2: 2–14.

[19] Head, M.A., Barson, R. and Bonney, M.C. 1987. A Petri-net representation of computer production management, in: P.F. McGoldrick (Ed.) Proc. 3rd NCPR Conf., Nottingham. Kogan Page, London, pp. 251–256.

[20] Bonney, M.C. and Head, M.A., 1993. Progress on developing a framework for computer aided production management. Int. J. Prod. Econom., 30-31: 345–353.

[21] Bonney, M.C., Barson, R.J., Head, M.A. and Huang, N., 1992. UNISON – A tool for enterprise integration, in: C.J. Petrie (Ed.), Proc. 1st Int. Conf. on Enterprise Integration Modelling. MIT Press, pp. 239–248.

[22] Bonney, M.C., Barson, R.J., Head, M.A. and Huang, N., 1992. UNISON – A tool for enterprise integration. Presented at 1st Int. Conf. on Enterprise Integration Modelling Technology (ICEIMT). Hilton Head, South Carolina, 8–12 June 1992.